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Original Article

EFFECT OF COOLED EGR TECHNIQUE ON PERFORMANCE AND EMISSIONS OF CRDI ENGINE OPERATED WITH BIODIESEL BLENDS

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ABSTRACT

Hazardous pollutants and limited sources of fossil fuels made power dependent sectors to focus on alternative sources. However, complete replacement is still constrained and challenging. Attempts to assure complete replacement were more or less fulfilled by biodiesels. In this article, trials made on EGR associated single cylinder CRDI engine with blends of Jatropha and Rice-bran biodiesels are discussed. Set of readings obtained under the split injection system of mass 10% pilot fuel and 90% main fuel maintained at 300 bars with dwell of 10^o and 15% of cold EGR are examined. Results obtained show, brake thermal efficiency is higher at peak load for RJD-II sample than RJD-I sample, whereas specific fuel consumption is same. Sample RJD-I has indicated highest break mean effective pressure at full load which influenced mechanical efficiency. Remarkable changes observed in emissions indicate 11.7% and 16.6% reduction in CO for RJD-I and RJD-II, respectively. NO_x discharge reduced up to 5.5% and 7.7% for RJD-I and RJD-II, respectively. CO_2 products are 6.6% and 8.6% higher for RJD-I and RJD-II respectively than diesel.

KEYWORDS: Pollution, EGR, CRDI, Split injection & RJD-I and RJD-II

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NOMENCLATURE

CRDI: Common Rail Direct Injection

RJD-I: Composition of 10% Rice bran biodiesel, 10% of Jatropha biodiesel and 80% neat Diesel.

RJD-II: Composition of 15% Rice bran biodiesel, 15% of Jatropha biodiesel and 70% neat Diesel.

EGR: Exhaust Gas Recirculation

ASTM: American Society for Testing and Materials

INTRODUCTION

Both transport sector and economic growth of the country are interrelated, which directly influence the demand for portable energy sources. Meanwhile road, rail, sea and aviation depend on affluence of fossil sources. Environmental sustainable practices in the manufacturing technology of automobiles have many challenges, whereas replacement of fossil fuels with alternatives is still nightmare. Portable fossil liquid energy sources are

compensated with biodiesels, which are recognized for their proven results. Numerous studies on biodiesels are based on their ability to fulfil norms of fossil sources.

Urban air quality management always pitch by growth of on road transport of two wheelers and light motor passenger vehicles. In India, newly registered vehicles contribute 70-80% of CO_2 and NO_X emissions at national level. Abnormal operating conditions of automobile from traffic contributed 31 to 57% of CO_2 and NO_X respectively [1]. It is estimated that transport sector's contribution to air pollution in terms of CO_2 is increasing by 4-6% per year, which leads to about seven times by 2050. Promised results were derived with Jatropha biodiesel blends with increased efficiency and reduced emissions [3].

Blends of Karanja and castor biodiesel of various proportions have directly influenced in reducing emissions, whereas slight decrement in thermal efficiency was recorded [4].

Results obtained from light duty diesel engine supplied with used cooking sunflower oil and fresh sun flower oil biodiesel blends have shown reduced emissions, except oxides of nitrogen (NO_X) [5]. Investigation on diesel engine with blends of Jatropha and fish waste biodiesels have given lower emissions, but oxides of nitrogen were higher compared to diesel fuel [6]. Numerical validation of different biodiesels in which average emissions were reduced by 4%, 15.6%, 43.3%, 3% and 37% for soya bean, jojoba curcas, veal oil, grease oil and pentanol, respectively [7]. Direct injection diesel engine fuelled with Jatropha biodiesel have given smooth performance with slightly improved efficiency and reduced CO, CO_2 emissions [8]. Addition of Jamun seed powder and Jackfruit seed powder directly into diesel has shown improved performance up to certain limit and also influenced reduction in NO_x [9]. Exhaust gas recirculation techniques have influenced possessively by reducing 10% of oxides of nitrogen emissions from the engine, running with waste plastic derived oil [10]. Improved combustion characteristics were obtained from the diesel engine operating with EGR alcohol additives, which shows enhancement of heat release rate, premixed combustion phase that directly influenced indicated thermal efficiency [11]. Black solder fly impacted negatively on decreasing NO_X emissions. Higher NO_X emissions recorded under 10% and 20% blends compared to diesel [12].

Blends of Karanja oil up to 50% on single cylinder compression ignition engine at various pressures have indicated slight improvement in BTE and 20% of higher NO_x than the diesel [13]. Formation of carbon deposits were found with pyrolytic biodiesel, which also shows improved BTE at 30% blend [14]. Biodiesels of animal fat extraction have given remarkable reductions in emissions except NO_X [15]. CRDI operating at higher fuel injection pressures and higher fuel injection timings showed improved thermal efficiency with reduced hydrocarbons and oxides of nitrogen [16]. Mahua methyl ester on CRDI engine at higher fuel injection pressure has revealed better combustion characteristics, which results in increased BTE with decrease in emissions [17]. Plastic derived biodiesels up to 30% blend have increased BTE by 3%, which has decelerated after 20% of EGR aid to reduce NO_X emissions [18]. Honge biodiesel on CRDI – EGR setup operating with split injection at 900 bar and 15%. Exhaust gas recirculation has resulted in higher BTE and reduced emissions [19]. Reduction in specific fuel consumption and emissions were recorded for CRDI fuelled with lemon peel biodiesel blend under 10% cooled EGR [20]. Higher EGR flow rates show adverse effects on BTE of light duty diesel engine, whereas 5% and 10% of EGR have enhanced combustion characteristics [21]. The exhaustive survey of the literature directly triggers the suitability and inadequacy of alternative sources, which are to be essentially rectified through additional improvements and trials. Hence, this research work concentrates on replacement of fossil fuel as well as controlling of toxic cocktails through EGR technique.

MATERIALS AND METHDOLOGY

Sample Preparation and Characterization

Samples are prepared by blending different proportion of biodiesels directly with diesel. Readily available Jatropha and rice bran biodiesel produced by transesterification process were purchased from open market (Chennai vendor). Sample with 10% of Jatropha, 10% of Rice bran and 80% of Diesel is named as RJD-I and 15% of Jatropha, 15% of Rice bran with 70% of Diesel is named as RJD-II. Samples were characterized under ASTM standard procedures. Characteristics of samples are found in margin with diesel which encouraged for null modification in existing engine system. Characterized results are compared with 100% diesel and tabulated in table 1.

Table 1: Sample Properties

Properties	Diesel	RJD-I	RJD-II
Calorific value (MJ/kg)	42.5	41.6	41.15
Density (kg/m^3)	830	862	876
Flash point (^{0}C)	65	78	86
Viscosity (cST)	4.59	4.61	4.92

Experimental Setup

Investigations are carried out on computerized single cylinder CRDI engine having split injection system and provided with cooled exhaust gas recirculation of 15% constant mass flow rate. Detailed specification of setup is provided in table 2. Performance readings captured and tabulated with the help of "enginesoft" software. Emission ranges are collected from AVL 437C smoke meter and AVL DIGAS 444N exhaust analyser. Figure 1 and 2 show engine setup view from front and top, respectively. Detailed line diagram of setup layout is shown in figure 3.

Table 2: Engine set up Specification

Parameter	Specification
Make	Kirloskar
No of cylinders / strokes	One / 4
Power / Speed / Compression ratio	3.5 kW / 1500 RPM / 17.5
Stroke length / Cylinder bore / Swept volume	110 mm /87.5 mm /661.45 cc
Coolant	Water
Dynamometer	Eddy current
ECU	Model Nira i7r with programmable ECU software and calibration cable
EGR	Water cooled
Injector	Solenoid driven

Figure 1: Front View of Setup

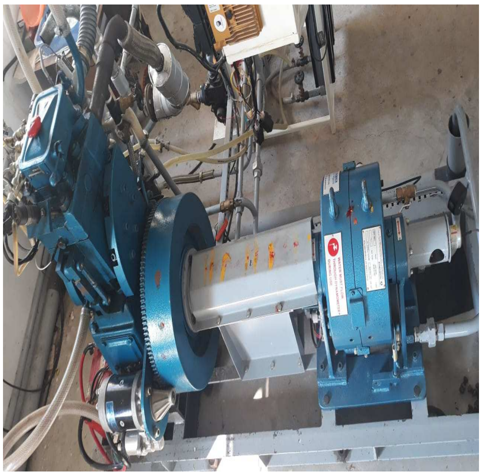

Figure 2: Top View of Setup

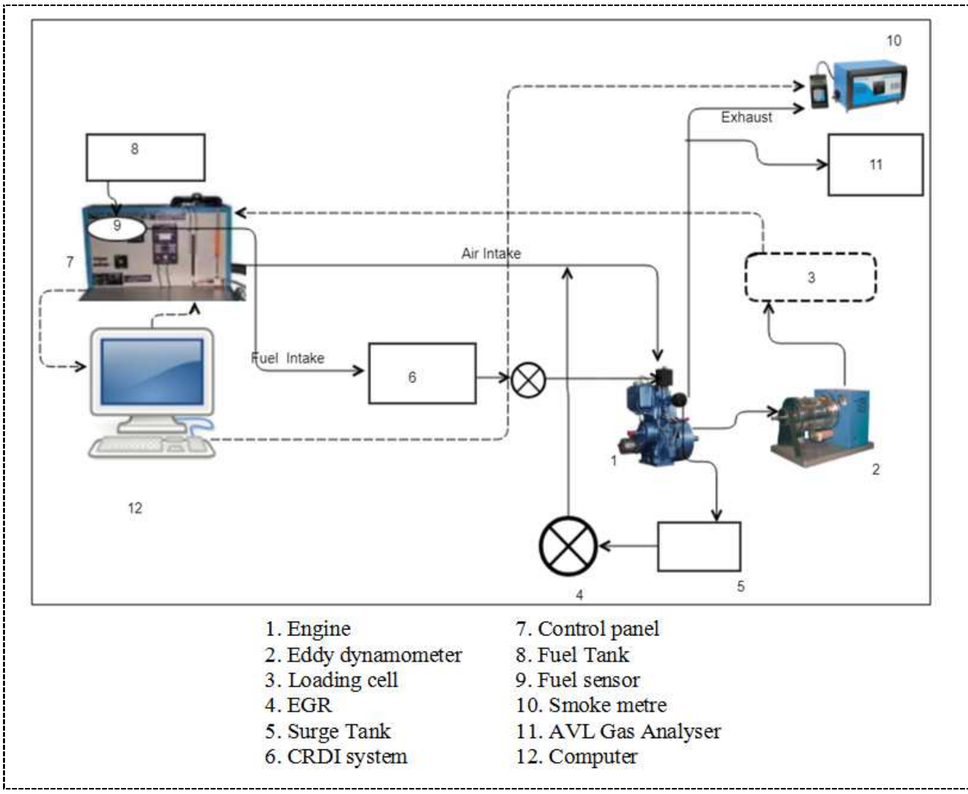

Figure 3: Schematic of Experimental Setup

EXPERIMENTAL APPROACH

The performance and emission attributes of diesel, RJD-I and RJD-II are recorded at 0, 25, 50, 75 and 100% load conditions with the injection pressure of 300 bars. The split injection system maintained at the dwell of 10^o of crank angle injects 10% of pilot fuel 30^o before top dead centre and 90% of main fuel 20^o before top dead centre. Samples are kept at separate tanks, which are connected to high pressure CRDI pump. EGR system is calibrated with hot dry air and set into 15% of flow rate later, which is connected to exhaust pipe. Fuel lines are cleaned and water supply is regulated to 200 litres per hour. Readings are captured at steady state, maintaining the 15 minutes of interval. Every possible care has been taken while recording various data.

Error Analysis

Uncertainty in results obtained must be analysed, so that reliable and consistency of the data can be justified. Potential of the measuring instruments without error is impossible but optimized data can be derived. Hence, accuracy of the data is verified with the Holman procedure and tabulated with range, accuracy and percentage of uncertainty in table 3.

Table 3: Instruments with Accuracy and Uncertainties

S. No.	N	Data	Range	Accuracy	Uncertainties
1	Pressure sensor	Pressure	0-110 bar	±1 bar	±0.1
2	K type temperature indicator	Temp.	0-1200 ° C	±1□	±0.12
3	Speed measurer	Speed	0-9999 rpm	±10rpm	±1.0
4	Torque indicator	Torque	0-100 Nm	±0.1 N-m	±0.2
5	Fuel flow rate gauge (weight loss type)	Fuel flow	0-999 kg/h	±0.02 kg/h	±0.13
6	Gas analyser	CO	0-10%	±0.03%	±0.2
		CO_2	0-20%	±0.03%	±0.13
		HC	0-20000 ppm	±15 ppm	±0.2
		NO_x	0-5000 ppm	±20ppm	±0.2

By using equation $\sqrt{(U1)^2+(U2)^2+(U3)^2+(U4)^2+(U5)^2+(U6)^2}$, where U1 is uncertainty of instrument S. No. 1, U2 is uncertainty of instrument S. No. 2, and so on. From this equation, an average uncertainties value is found to be ±2%, which is quite acceptable.

RESULTS AND DISCUSSIONS

Cooled EGR system and CRDI aided engine are used to make an explorative test with prepared samples. Performance characteristics and exhaust parameters are plotted under Split injection of 10^o dwell at stable speed and various load conditions. Some of the important performance parameters and emission plots are glanced briefly.

Brake Thermal Efficiency

Deviation of brake thermal efficiency with brake power is shown by figure 4, which clearly indicates that brake thermal efficiency expands with brake power. From plot, it is observed that diesel has more BTE at all loads, which is the function of calorific value. As diesel has higher calorific value, it has directly impacted on brake thermal efficiency. At peak load, brake thermal efficiencies for Diesel, RJD-I and RJD-II samples are 36.25%, 32.06% and 32.4%, respectively.

Notable point from plot is that RJD-I has maintained consistency of percentage, which lies between diesel and sample RJD-II which suddenly fall down at peak load, whereas sample RJD-II shows more thermal efficiency than that of RJD-I due to increase in oxygen availability with split injection system, which directly enhances chemical reactions.

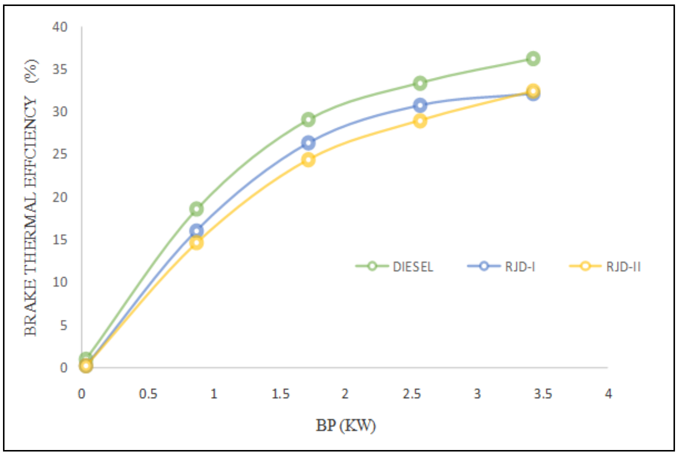

Figure 4: Variation of Brake Thermal Efficiency with Brake Power

Specific Fuel Consumption

Specific fuel consumption is an important parameter that directly impacts on engine performance and defines the engine capacity in terms of fuel economy. Figure 5 indicates fuel consumption rate at various loads. From the results obtained, it is observed that diesel and sample fuels have consumed more fuel at no load, and this gradually decreases with increase in load. Due to higher viscosity and lower calorific value which attributes for quenching phenomenon at full load, sample RJD-I and RJD-II were spent more compared to diesel. At no load, engine consumes less sample fuels compared to diesel because of oxygen availability that boosted better rate of chemical reaction. CRDI system influence is observed at moderate load, which is indicated by overlapping of diesel and sample RJD-I value. Fuel economy of samples RJD-I and RJD-II found same, which is 8% more than that of diesel at rated load.

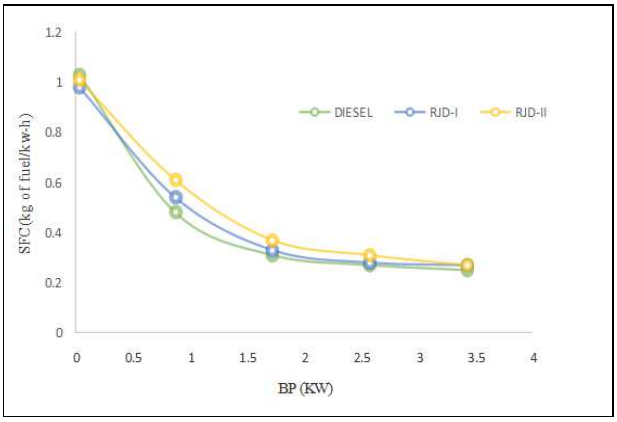

Figure 5: Variation of Specific Fuel Consumption with Brake Power

Mechanical Efficiency

Energy generated and energy used to produce mechanical work specifies engine energy transmission capacity, which is calculated from mechanical efficiency. Figure 6 indicates deflection of stated capacity of engine with load for its shaft work. From plot, it is clear that RJD-I sample stands first at its shaft work. At peak load, mechanical efficiency of sample RJD-I is 4.5% more than the diesel and sample RJD-II is almost margin with diesel. The fuel property of RJD-I, which is in compensation of diesel and RJD-II, has influenced this parameter. Moderated calorific value and high pressured split spray of fuel directly affect the mechanical efficiency through mean effective pressure.

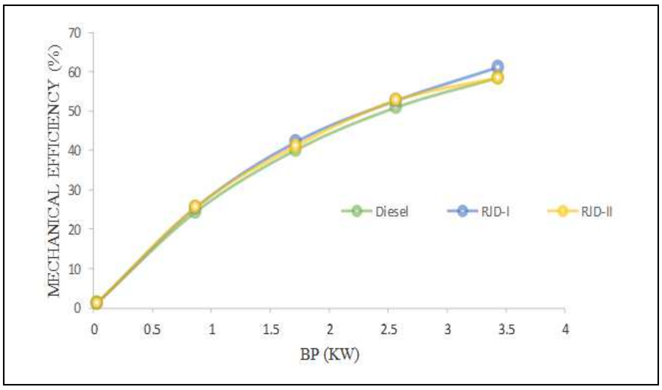

Figure 6: Variation of Mechanical Efficiency with Brake Power

Exhaust Gas Temperature

Random availability of fresh oxygen due to split spray and combustion temperatures will enhance hydrocarbons to continue their chemical reactions even after opening of exhaust valve. Considerable amount of available energy will be liberated to atmosphere, which affects engine performance and emissions.

Figure 7 indicates variation of exit hot gas temperature with load. From the figure, it is clear that sample RJD-II has less exhaust energy compared to diesel and sample RJD-I. Exhaust gas temperatures are influenced by many factors such as calorific value, availability of oxygen, combustion chamber design and cooling effects. Diesel has highest calorific value which leads to higher temperature at peak load. At no load, exit temperature of sample of RJD-I is 6.3% more than diesel due to oxygen associated with fuel is more and calorific value is in range with diesel, whereas at peak load, it is 2.3% less than diesel because of EGR that dilutes oxygen quantity and also combustion chamber temperature.

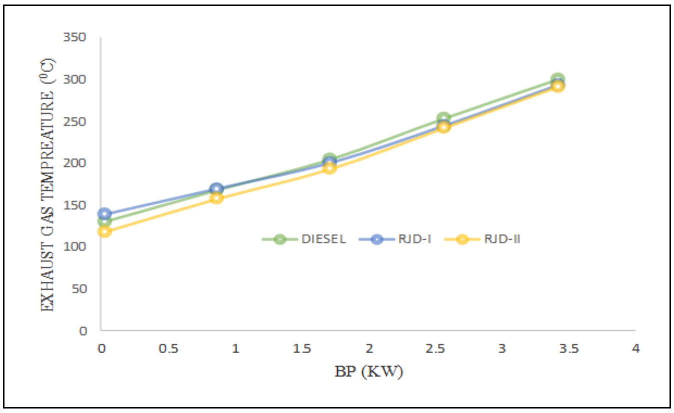

Figure 7: Variation of Exhaust Gas Temperature with Brake Power

Carbon Monoxide

Exhaust consists of low concentrated carbon monoxide, which increases gradually with load. Capricious distribution of charge and lack of time at peak load influence the emission of CO. Figure 8 shows fluctuation of CO emissions with load. Percentage of hydrocarbon fuel in sample RJD-II is less which leads for lower CO emissions at peak load. However, diesel is having lowest CO emissions at no load and highest CO emissions at full load. At no load, diesel, RJD-I and RJD-II samples emit 0.026%, 0.08%, 0.059% of CO, respectively. At full load, sample RJD-II in found to have about 29% less CO emissions compared to diesel.

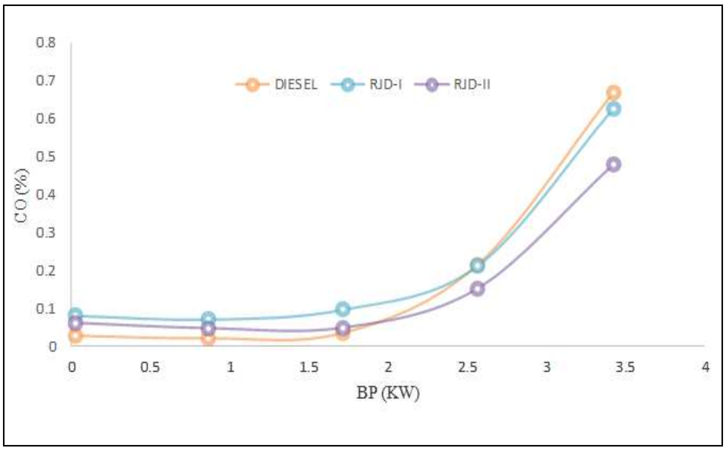

Figure 8: Variation of CO Emissions with Brake Power

Unburnt Hydrocarbons

Quenching phenomenon due to split injection and cold exhaust recirculation plays an important role to make original fuel molecules to come out with exhaust. Ignition delay cannot be optimum because of split injection, which also directly impact on HC existence. Figure 9 shows formation of HC in ppm with load. From plot it is observed that diesel is having highest HC at no load and at full load. From the curves obtained, it is clearly understood that as diesel concentration is decreased, HC emissions are decreased. At half load sample RJD-I has highest HC emissions because of rich mixture. Sample RJD-II with 30% biodiesel blend shows consistency and lowest HC emissions which is 16% less than that of diesel.

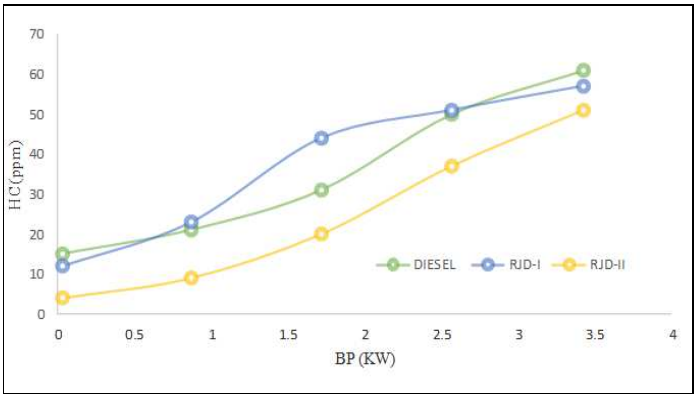

Figure 9: Variation of Unburnt Hydrocarbons with Brake Power

Carbon Dioxide

Intermittent availability of oxygen during combustion leads to formation of CO_2. Aid of EGR also contributes to boosting of CO_2 emissions. From figure 10, it is observed that sample RJD-I and RJD-II both shown higher CO_2 emissions because of enriched oxygen. Sample RJD-II having 30% of biodiesel blend shown highest CO_2 emissions among all fuels experimented at full load, which is 8.6% higher than diesel.

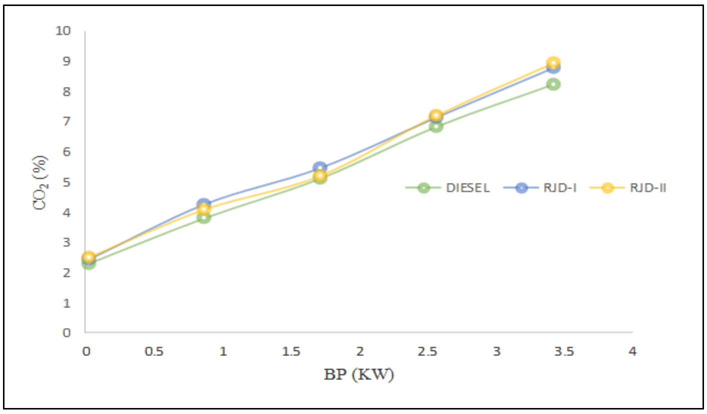

Figure 10: Variation of Carbon Dioxide with Brake Power

Oxides of Nitrogen

Oxygen from air and biodiesel at higher temperatures form suitable environment to form oxides of nitrogen. Hence, exhaust recirculation is used to replace or reduce domination of oxygen by insertion of CO_2 and H_2O. Figure 11 shows variation of NO_x formation in terms of ppm at different loads. 15% of total exhaust, which is cooled, is recirculated to combustion chamber through air intake line, which quenches the combustion environment and replaces oxygen quantity. From plot, it is seen that sample RJD-II has NO_x emissions, which is 7% less than that of diesel and 2.3% less than the RJD-I at full load.

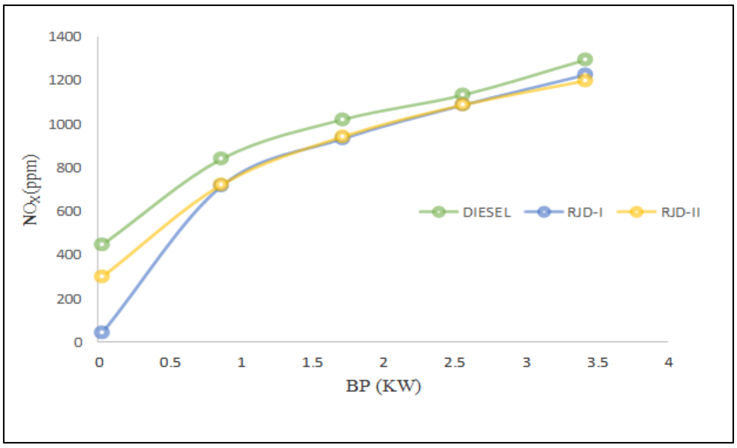

Figure 11: Variation of Oxides of Nitrogen with Brake Power

CONCLUSIONS

From plots and data, it is summarised that the brake thermal efficiencies obtained by blended fuel samples are less than that obtained by diesel fuel. Sample RJD-I has shown optimistic outcomes, whereas RJD-II outstripped at peak load. Fuel economy of samples RJD-I and RJD-II found same, which is 8% more than that of diesel at rated load.

Shaft power for particular fuel consumption is more for sample RJD-I, which has higher conversion percentage at all loads. Percentage of energy transmission from source to end is almost equal with diesel at rated load. Energy interaction through exhaust gases is more for diesel and almost equal for both the samples at peak load, which enhances quality of availability.

At no load, CO emissions are more compared to diesel, which is reversed at full load. Increase in percentage of biodiesel decreased the percentage of CO emissions. HC emissions are less for both samples at peak load. Sample RJD-II has HC emissions, which is due to increased blend ratio and lower heating value.

CO and CO_2 emissions gradually increase with load. It is observed that CO emissions are less, and CO_2 emissions are more than diesel at rated load. Oxides of nitrogen are more for diesel at all loads. Diluting of oxygen and quenching of combustion chamber by cooled EGR has direct effect on NO_x emissions. At rated load, sample RJD-II has lowest and diesel has highest NO_x emissions.

From the above discussion, it is concluded that performance parameters of samples are in margin with each other and less than that of diesel. Sample RJD-II has given optimistic values in emission except CO_2 plots, which clearly specify that 30% biodiesel blend sample RJD-II is the preferable alternative fuel sample for engine specifications mentioned in table 2 with 15% cooled EGR.

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